802.3bp Sleep/Wake-up Specification

TC10 - OPEN Sleep/Wake-up Specification for Automotive Gigabit Ethernet

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<td>Cliff Fung</td>
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Introduction
This specification defines new service primitives provided by the ISO/OSI layer 1 (PHY) and supporting a controlled link shutdown and a fast global wake-up within an Ethernet network. Higher layers like the network management can access those service primitives to realize partial networking, where selected parts of a network are inactive. The coordination of switching off selected nodes of a network is handled by the network management and is not part of this specification. This partial networking concept relying on selective link shutdown and fast global wake-up is especially suited for automotive Ethernet networks.

The 802.3-2018: 1000Base-T1 specification does not define mechanisms for a controlled link shut-down and wake-up. Therefore the new service primitives defined in this specification can be regarded as a supplement to the 802.3-2018: 1000Base-T1 specification.

The new services primitives make use of LPS, WUR and WUP commands. When not using the new service primitives and commands, implementation of these extensions will not impact the interoperability to a “basic” 802.3-2018: 1000Base-T1 PHY.
1 Scope

The following are the objectives of the Sleep/Wake-up specification:

a) Comply with the CSMA/CD MAC
b) Comply with the specifications for the xMII (MII, RMII, RGMII etc.)
c) Support global network wake-up (incl. link start-up time) within less 250ms
d) Support wake-up process completely covered in ISO/OSI layer 1
e) Support controlled link shutdown to deactivate selective parts of network
f) Comply with Autosar network management
g) No unwanted wakeup in presence of interference noise
h) Applicable for 1000BASE-T1

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Amendment 4: Physical Layer Specification and Management Parameters for 1Gb/s Operation over a Single Twisted-Pair Copper Cable”, IEEE Std 802.3-2018

3 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

4 Wakeup/Sleep electrical interface

PHYS supporting wakeup and sleep signalling over dedicated I/O pins should follow the following guidelines. Sleep/wakeup commands are not part of the xMII interface.

The following list shows examples of pins typically associated with wakeup and sleep functionality. Depending on the type of device and functionality not all pins are relevant.
Table 1 Example of wakeup related device pins

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<tr>
<th>Pin name</th>
<th>Direction¹</th>
<th>Function</th>
<th>Voltage Source</th>
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<tr>
<td>INH</td>
<td>OUT (Wired-OR)</td>
<td>Prevent external regulator from shutdown</td>
<td>VDD_AO</td>
<td>Recommended</td>
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<td>LOCAL_WAKE</td>
<td>IN</td>
<td>Local wake input</td>
<td>VDDIO¹ or VDD_AO</td>
<td>Yes</td>
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<td>WAKE_FWRD</td>
<td>OUT</td>
<td>Wake</td>
<td>VDDIO or VDD_AO</td>
<td>No</td>
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<td>WAKE_IN_OUT</td>
<td>IN/OUT (Wired-OR)</td>
<td>Multiplex interface to support wake input and output over the same pin</td>
<td>VDDIO or VDD_AO</td>
<td>No³</td>
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<td>VDD_AO</td>
<td>IN</td>
<td>Always-on supply, available during sleep to power wakeup detection functionality</td>
<td>VBAT or other available standby supply</td>
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</table>

The interface shall support a local-wakeup input and may support a wakeup-forwarding output. For multi PHY designs these pins can be joined. Inhibit pins should be a high-side switch, which is pulling INH high during normal operation and high-Z during sleep. A dedicated wakeup-forwarding pin must be active-high.

The I/O voltage is left to the implementer. Note that INH is supplied by a standby supply which is available during sleep.

In some automotive use-cases a glitching wakeup source is connected to the LOCAL_WAKE pin. In order to support such applications it is required to implement a detection threshold. Pulses with a duration of less than 10 us must not be detected as wakeup event and are to be ignored. A pulse duration of more than 40 us must be guaranteed to be detected and cause a wakeup. Note that pulses in this interval are undefined.

¹ From the perspective of the DUT
² Standard JEDEC voltage level recommended, no specific voltage level given in this spec
³ WAKE_IN_OUT can optionally be used to replace dedicated LOCAL_WAKE and WAKE_FWRD and merge the functionality into a single pin.
From this follows that a local wakeup output pulse (originating from WAKE_IN_OUT, WAKE_FWD or another source) must have a duration of at least 40 us to be reliably detected.

In case LOCAL_WAKE is fed through the wiring harness (support for slow legacy wake-up line) it is recommended to have the option to increase the rejection window (minimum of 10 ms).

*) optionally other values may be supported
5  Power consumption

The following guidelines on the device power consumption in sleep mode target typical Ethernet products such as single and multiport PHYs and switches.

A single-port PHY product should have a quiescence current of 35\textmu{A}. A multi-port PHY or switch product should have a quiescence current of 25\textmu{A} plus 10\textmu{A} for each port\(^4\).

6  Timing Behavior

The sleep and wake up process in a PHY shall fulfill the following requirements\(^5\):

6.1  ACK\(_\text{timer}\)

The time duration in SLEEP\_ACK state shall expire in 8ms.

\[\text{ACK\(_\text{timer}\) = 8 ms.}\]

6.2  REQ\(_\text{timer}\)

The time duration in SLEEP\_REQUEST state and SLEEP\_SILENT state shall expire in 16ms.

\[\text{REQ\(_\text{timer}\) = 16 ms.}\]

6.3  TWU\(_\text{Link\_passive}\)

The wake-up transmission time over a passive link (WUP) shall be less than 2 ms.

\[\text{TWU\(_\text{Link\_passive}\) < 2 ms.}\]

6.4  TWU\(_\text{Link\_active}\)

Wake-up transmission time over an active link (WUR) shall be less than 2 ms.

\[\text{TWU\(_\text{Link\_active}\) < 2 ms}\]

6.5  TWU\(_\text{Forwarding}\)

For multiport devices it is possible to forward a wakeup from one physical port to another physical port. The Wake-up forwarding time is the time from receiving a wakeup Wakeup\_Forward.Indication on one physical port until a Wakeup\_Forward.Request is generated on another physical port.

Wake-up forwarding time shall be less than 1 ms.

\[\text{TWU\(_\text{Forwarding}\) < 1 ms}\]

For a passive device, the time from Wakeup.request on the initiating device to Wakeup.Indication on the responding device is:

\(^4\text{More complex SoC products with other wakeup-capable interfaces may exceed these numbers, while still meeting this specification.}\)

\(^5\text{For the mentioned timer values a 10\% tolerance is expected.}\)
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TWU_Link_Passive + T_Powersupply_stable + T_Initialization,

Where T_Powersupply_stable is the time from which the passive device requests power until the power supply is stable.

T_Initialization the time from when the power supply’s stable voltage is reached until Wakeup.Indication is generated.

The sum of T_Powersupply_stable and T_Initialization shall be less than 15ms

6.6 TWU_WakeIO

The time TWU_WakeIO is defined from the generation of a Wakeup.request in one device to the reception of the corresponding Wakeup.indication in the other device when both devices are connected by using the electrical wakeup interface pins (for instance WAKE_FWRD or WAKE_IN_OUT).

TWU_WakeIO < 1 ms

7 Service Primitives and Interfaces

Beside the service primitives and interfaces, specified in IEEE802.3, new service primitives are provided by the 802.3 physical layer to the upper management layer. These services are needed to realize the sleep and wake-up behaviour.

The wakeup and sleep control information is transferred between the PMA, PCS and SMI and physical device pins. This document does not specify an SMI address layout.

7.1 Sleep.request

The purpose of the Sleep.request service primitive is to shut down a link in a controlled manner, without generating unwanted link failure interrupts.

7.2 SleepForce.request

The purpose of SleepForce is to force the device into Sleep state bypassing the sleep handshake.

7.3 Sleep.indication

The purpose of the Sleep.indication service primitive is to indicate a received sleep request.

7.4 SleepFail.indication

The purpose of the optional SleepFail.indication service primitive is to indicate an aborted or unsuccessful sleep handshake.

7.5 SleepAbort.request

The purpose of the SleepAbort.request service primitive is abort a received sleep request.
7.6 Wakeup.request
The purpose of the Wakeup.request service primitive is to generate a WUP or WUR command leading to a global wake-up within the Ethernet network.

7.7 Wakeup.indication
The purpose of the Wakeup.indication service primitive is to indicate a detected wake-up event. This includes a wake-up over a passive link, a wake-up over an active link as well as over a local wake-up pin. A Wakeup.indication can originate from MDI side (as WUP or WUR), from SMI side (over wake-up register) or over a physical pin (WAKE_IN, WAKE_IN_OUT).

7.8 Inhibit.indication
Signals the state of an optional power supply inhibit interface.

7.9 WakeupForward.indication
(optional)
This service primitive signals that a Wakeup forwarding event has been received over wake I/O functionality or MDI.

7.10 WakeupForward.request
(optional)
This service primitive signals that a wake-up event has been forwarded to this port as a consequence of a WakeupForward.indication on another port or through the wake I/O functionality.

8 Command Definitions
This specification defines three commands which are used to request a power down and signal a wake-up over an active as well as a passive link for 1000BASE-T1.

8.1 Low Power Sleep (LPS) and Wake-Up Request (WUR)
The Low Power Sleep (LPS) is a command to indicate a sleep request to the link partner. The LPS command is sent by a node requesting a transition to SLEEP, while the link is up.

The Wake-Up Request (WUR) is a command to indicate a wake-up request to the link partner. It can be sent by a node PHY or switch PHY to distribute the wake-up request over a link, which is already active.

The LPS and WUR are encode in 1000BASE-T1 PCS level Operations, Administration, and Maintenance (OAM). The OAM Frame is shown as follow:
The bits LPS and WUR are defined as follows:

\[ LPS = (tx_{lps} = TRUE) \& (loc_{wake}_{req} = FALSE) \& (link_{status} = OK) \& !tx_{lps}_{done} \]

\[ WUR = (tx_{lps} = FALSE) \& (loc_{wake}_{req} = TRUE) \& (link_{status} = OK) \]

An LPS and WUR command is transmitted through transmitting a single OAM frame with the respective bit set. Transmission of LPS and WUR does not utilize the OAM handshaking signals (Valid, Toggle, Ack, TogAck) and thus reception of the command is not acknowledged through the OAM handshaking mechanism\(^6\).

Bits D5 and D4 of Symbol 0 must remain reserved (value always 0) at MDIO level. Register reads and writes as part of the 1000BASE-T1 OAM message transmit and receive registers with respective bits set must have no effect on WUR/LPS.

### 8.2 Wake-Up Pulse (WUP)

The Wake-up pulses (WUP) is a command to indicate a wake-up request to the link partner. The wake-up pulse is transmitted if tx_mode is set to SEND_WUP as indicated in modified PHY Control State Diagram.

The pattern which is transmitted shall be identical to the side stream scrambler used in nominal IEEE 802.3bp tx_mode = SEND_T with the scrambler configured to operate in master mode. The symbol rate shall be 62.5

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\(^6\) Acknowledgement happens on wakeup-sleep handshake-level by responding with a LPS command.
MBaud. The differential output voltage over an 100 ohms differential load shall be 1.15V +/- 0.15V peak to peak (with maximum limited per IEEE 97.5.3.5).

The duration of wake-up pulse duration is 1ms +/- 0.3ms to allow reliable detection. The energy detection of a WUP command is left to the implementer.

PHYS with multi-speed capabilities shall use the specified WUP pattern corresponding to the speed the PHY is configured to operate in. The speed configuration process depends on the application and can be through means of pin-strapping, autonegotiation result, register configuration, OTP fuses or similar.

If WUP is sent prior to autonegotiation results are available, then WUP should be the minimum speed advertised by the autonegotiation.

Note, it is only guaranteed that a WUP can be detected reliably if the responder PHY devices supports and operates in the WUP associated speed mode.\(^7\)

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\(^7\) For example, a WUP transmitted by a PHY operating in 100BASE-T1 mode is not guaranteed to be detected by a 1000BASE-T1 device and vise-versa.
9 Modified PMA and PCS IEEE802.3bp

This section describes the modification of the Physical Media Attachment and Physical Coding Sublayer of IEEE802.3bp. These modifications are to make the Sleep/Wake-up specification be applicable for 1000Base-T1.

9.1 PHY power modes

The following state diagram shows the power state machine which implements the two-way handshake protocol.

![Figure 3 PHY power mode state diagram](image)

9.1.1 PHY reset and initialization

After a device reset the PHY may automatically assert loc_wake_req. This triggers a WUP transmission before normal training is performed.

9.1.2 Sleep

In case the link is up and Sleep.request is asserted the PHY will enter the Sleep Request state and will send LPS commands. The link partner receiving those LPS commands enters SLEEP_ACK state and starts sleep_ack_timer. If loc_sleep_abort is asserted, the sleep is aborted because of incoming data message. If sleep reject is not done, the link partner will enter SLEEP_REQUEST state and send LPS commands. If the PHY detects that it has sent and received LPS commands it transit to SLEEP_SILENT state and eventually to SLEEP. On the other hand, if the handshaking is not done before sleep_req_timer timeout, the PHY enters SLEEP_FAIL and back to SEND_DATA state.

9.1.3 Wakeup

The signalling of a Wakeup.request depends on the state of the link. If the link is up (tx_mode = SEND_N) the PHY will transmit a WUR command over the active link. If the link is down (link_control = DISABLE and
sync_link_control = DISABLE) the PHY may transmit a WUP pulse. If the link is not yet established
(loc_rcvr_status) for instance because the link is still in training (tx_mode = SEND_T) then a WUR command is
sent once the link is established.

The *Wakeup.indicate* shall be generated upon wakeup events. This service primitive is generated in any of the
following cases:

- The device is in sleep state and a WUP pulse (wup_recv) is received over MDI
- The link is up and a WUR is received (wur_recv) was signalled
- A local wakeup (loc_wake_req) is asserted

The implementation of the energy detection process that asserts wup_recv is left to the PHY vendor. The
energy detection process must not take longer than 2ms. It must be ensured that a transmitted WUP pattern
on the link reliably triggers the energy detection (wup_recv=TRUE).

### 9.1.4 Wakeup-forwarding

Multi-PHY devices (e.g. switches) or PHYs that implement WAKE_FWRD or WAKE_IN_OUT pins shall have a
selective wakeup forwarding mechanism. If a multi-PHY device detects a *Wakeup.Request in the form of
WUP/WUR*, it must be possible to forward the *indication* to one or multiple other PHYs of the device.

It shall be possible to forward a wakeup from the originating PHY to selectable target PHYs. On these target
PHYs the wakeup is send over MDI (as WUP or WUR, depending on the link status)⁸.

In case the device implements a WAKE_FWRD or WAKE_IN_OUT pin, a wakeup forwarding shall be indicated
by asserting the pin.

### 9.1.5 Variables

- **loc_act_detect**: Local activity detection signal. The variable is set to FALSE if consecutive symbols of zeros were received;
  otherwise set to TRUE. The value of loc_act_detect shall be set to TRUE (FALSE) within 1 us.
- **lps_recv**: Set if a LPS command was entirely received.
- **wur_recv**: Set if a WUR command was entirely received.
- **wup_recv**: Set if WUP pulses were sensed.
- **tx_lps**: If set, LPS bits are transmitted.
- **tx_lps_done**: Set after entire OAM frame (12 OAM symbol) containing the LPS command has been transmitted
- **lps_timer**: Timer used to ensure reliable transmission and decoding of LPS command. The timer shall expire 94.504us +/-
  0.936us (approximately +/- 1%)
- **lps_timer_done**: Set after lps_timer has expired
- **loc_sleep_req**: Set if a sleep is requested by the local PHY.
- **loc_wake_req**: Set if a wakeup is requested by the local PHY.

⁸ In case wakeup events arrive on multiple sources (e.g. pin and MDI) in a short interval, the wakeup event may be joint
into a single event.

Restriction Level: Public
802.3bp Sleep/Wake-up Specification Oct-21
sleep_req_timer_done: Set when the sleep_req_timer has expired.

sleep_ack_timer_done: Set when the sleep_ack_timer has expired.

loc_sleep_abort: Set if a remote sleep request is to be rejected while still in SLEEP_ACK phase

sleep_fail: Set if a sleep handshake was aborted by the link partner.

inhibit: Set if the (external) power supply shutdown is inhibited.

sleep: Set by the power state machine to notify PHY CTRL to disable transmission.

en_sleep_cap: Indicates whether sleep capability is enabled.

sleep_wait_timer_done: Set when sleep_wait_timer has expired.

### 9.1.6 Timers

**wup_timer**: A timer used to wait for reliable detection of WUP pulse. The timer shall expire 1ms +/- 0.3ms after being started.

**sleep_ack_timer**: A timer used in SLEEP_ACK state to check whether NM decides to reject sleep flow on an incoming data message or not. The timer shall expires 8ms after being started.

**sleep_req_timer**: A timer set up in SLEEP_REQ to check if the handshaking is properly done by both PHYs. If the PHY doesn’t enter SLEEP state before timeout, it enters SLEEP_FAIL state and back to NORMAL. The timer shall expires 16ms after being started.

**sendz_minwait_timer**: A timer to guarantee a minimum time SEND_Z is transmitted. The timer shall expire after 440 ns (+/- 80 ns).

**sendz_maxwait_timer**: A timer to limit the maximum number of SEND_Z transmissions to not trip the link partner’s PMA watchdog. This timer shall expire after 1.6 us (+/- 120ns).

**sleep_wait_timer**: A timer to limit the time to stay in SLEEP_WAIT state before going to SLEEP_FAIL state, if local_act_detect is always true during SLEEP_WAIT state. The timer shall expire after 4 us (+/- 120 ns).

### 9.2 PMA PHY Link Synchronization

The diagram below shows the modified link sync state machine.
9.2.1 Timers
link_sync_wd_timer: Link sync watchdog timer of 40 ms (+/- 400 us). When link_sync_wd_timer has expired, WUP pattern is transmitted in another attempt to wake up the link partner.

link_sync_break_timer: Link sync break timer of 30 us (+/- 300ns).

9.2.2 Variables
send_wup_req: The variable is set by Link synchronization state machine to request a retransmission of WUP pattern from the PHY control state machine.

tc10_start_link: Asserted by the PHY when it is ready to start link_sync or AutoNeg. The implementation is vendor specific.
9.3  PMA PHY Control State Diagram

The following Figure shows the Modified PMA PHY Control State machine which implements parts of the power sequencing state machine.

![Diagram of PMA PHY Control State Machine]

9.3.1 Variables

sleep : Set by the power statemachine to notify PHY CTRL to disable transmission.

AN_send_wup_req: Set by the AutoNeg arbitration state machine to request a retransmission of a WUP command.

send_wup_req: Set by the PHY Link Synchronization state machine to request a retransmission of a WUP command.

mr_autoneg_enable : controls the enabling and disabling of the Auto-Negotiation function.

auto_neg_imp : This variable indicates if an optional Auto-Negotiation sublayer is associated with the PMA.

link_control : Used by Auto-Negotiation to disable or enable PMA processing.

sync_link_control : Used by Link Synchronization to indicates the data source for the PMA transmit function.

9.3.2 Timers

sleep_req_timer : A timer set up in SLEEP_REQ to check if the handshaking is properly done by both PHYs. If the PHY doesn’t enter SLEEP state before timeout, it enters SLEEP_FAIL state and back to NORMAL. The timer shall expires 16ms after being started.

Restriction Level: Public

802.3bp Sleep/Wake-up Specification  Oct-21
wup_timer: This timer controls the duration for which WUP is transmitted. The timer shall expire 1ms +/- 0.3ms after being started.

### 9.4 Auto Negotiation state machine

The following Figure shows and Auto Negotiation state diagram with modifications for the sleep/wake up applications.

**Figure 6 AutoNeg Arbitration State Machine**

#### 9.4.1 Variables

- **AN_send_wup_req**: Set by the AutoNeg arbitration state machine to request a retransmission of a WUP command.
- **loc_wake_req**: Set if a wakeup is requested by the local PHY.
- **sleep**: Set by the power statemachine to notify Auto Negotiation and Link Synchronization to disable transmission.
- **tc10_start_link**: Asserted by the PHY when it is ready to start link_sync or AutoNeg. The implementation is vendor specific.
9.4.2 Timers

an_watchdog_timer: Autoneg watchdog timer to trigger WUP retransmission. Timer shall be 40 ms (+/- 400 us).

AN_break_timer: Autoneg break timer shall be 30 us (+/- 300 ns).